



US009066681B2

(12) **United States Patent**
Arts et al.

(10) **Patent No.:** **US 9,066,681 B2**
(45) **Date of Patent:** **Jun. 30, 2015**

(54) **METHODS AND SYSTEMS FOR ENHANCING
ULTRASONIC VISIBILITY OF
ENERGY-DELIVERY DEVICES WITHIN
TISSUE**

2019/5429 (2013.01); A61B 2018/1869
(2013.01); A61B 2017/3413 (2013.01);
(Continued)

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(58) **Field of Classification Search**

CPC A61B 18/04; A61B 2017/3413; A61B
2017/80; A01B 12/06

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USPC 606/33
See application file for complete search history.

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 127 days.

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(21) Appl. No.: **13/836,353**

CN 1103807 6/1995
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(22) Filed: **Mar. 15, 2013**

(Continued)

(65) **Prior Publication Data**

US 2013/0345553 A1 Dec. 26, 2013

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dated Nov. 13, 2013; 8 pages.

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Related U.S. Application Data

(60) Provisional application No. 61/664,555, filed on Jun.
26, 2012, provisional application No. 61/664,559,
filed on Jun. 26, 2012, provisional application No.
61/664,577, filed on Jun. 26, 2012.

Primary Examiner — Robert N Wieland

(51) **Int. Cl.**

A61B 18/04 (2006.01)

A61B 8/08 (2006.01)

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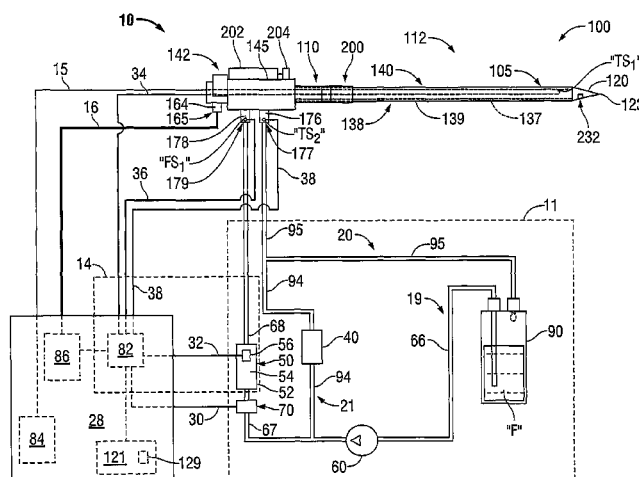
ABSTRACT

In accordance with aspects of the present disclosure, electro-
surgical systems are provided generally including at least one
energy-delivery device for delivering energy to tissue when
inserted or embedded within tissue. The energy-delivery
device can be a tissue ablation device, such as an ablation
probe, needle, etc. for ablating tissue as commonly known in
the art. The electrosurgical systems include at least one struc-
ture and/or operational characteristic for enhancing ultra-
sonic visibility of the energy-delivery devices within tissue
during ultrasonography.

(52) **U.S. Cl.**

CPC **A61B 8/0841** (2013.01); **A61B 18/1482**
(2013.01); **A61B 18/1815** (2013.01); **A61B**
2018/00023 (2013.01); **A61B 2018/00577**
(2013.01); **A61B 2019/5276** (2013.01); **A61B**

13 Claims, 6 Drawing Sheets



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| | A61B 18/00 | (2006.01) | | | | | | |
| | A61B 19/00 | (2006.01) | | | | | | |
| | A61B 17/34 | (2006.01) | | | | | | |
| | A61B 17/00 | (2006.01) | | | | | | |
| (52) | U.S. Cl. | | | | | | | |
| | CPC ... A61B18/1477 | (2013.01); A61B 2017/00084 | | | | | | |
| | | (2013.01); A61B 2017/00398 | (2013.01) | | | | | |
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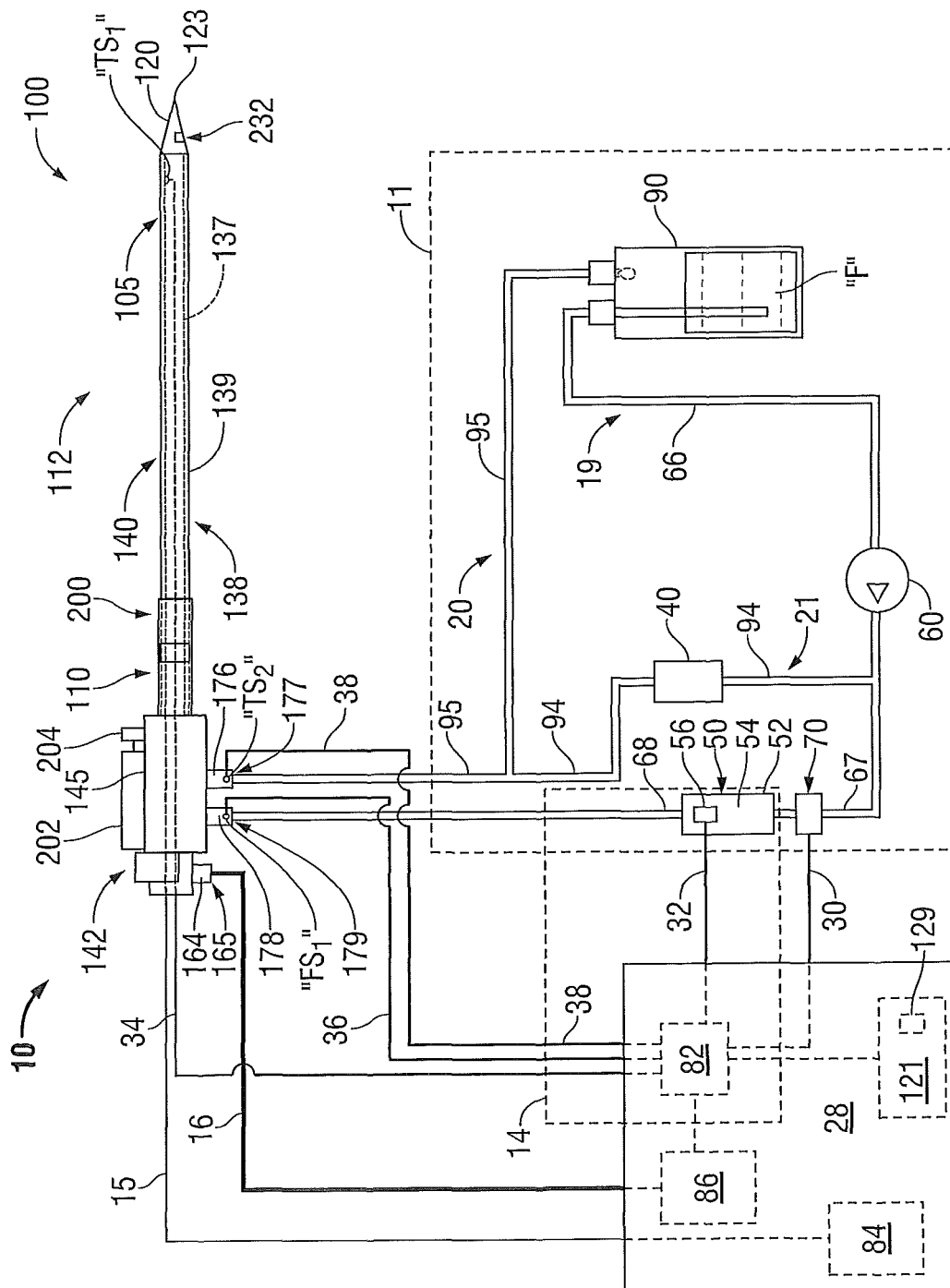


FIG. 1A

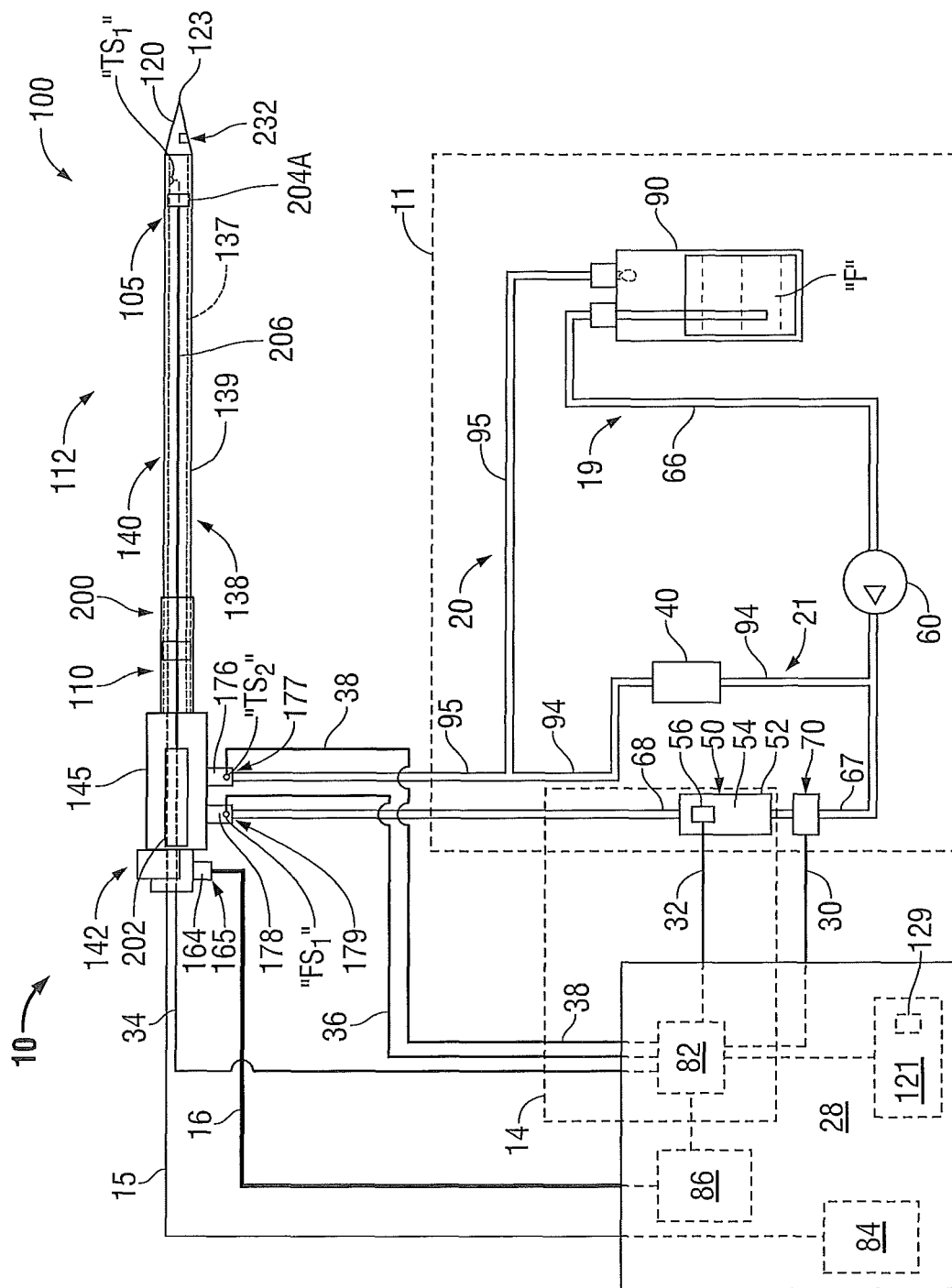


FIG. 1B

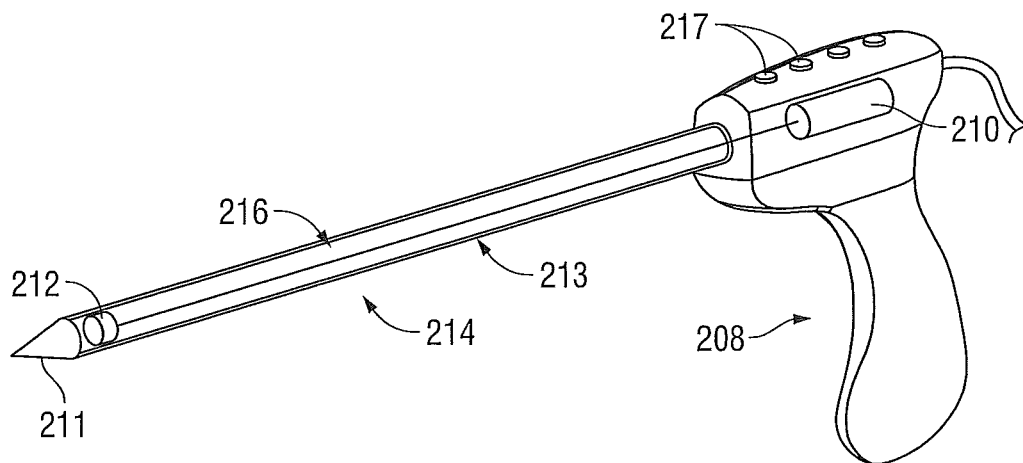


FIG. 2

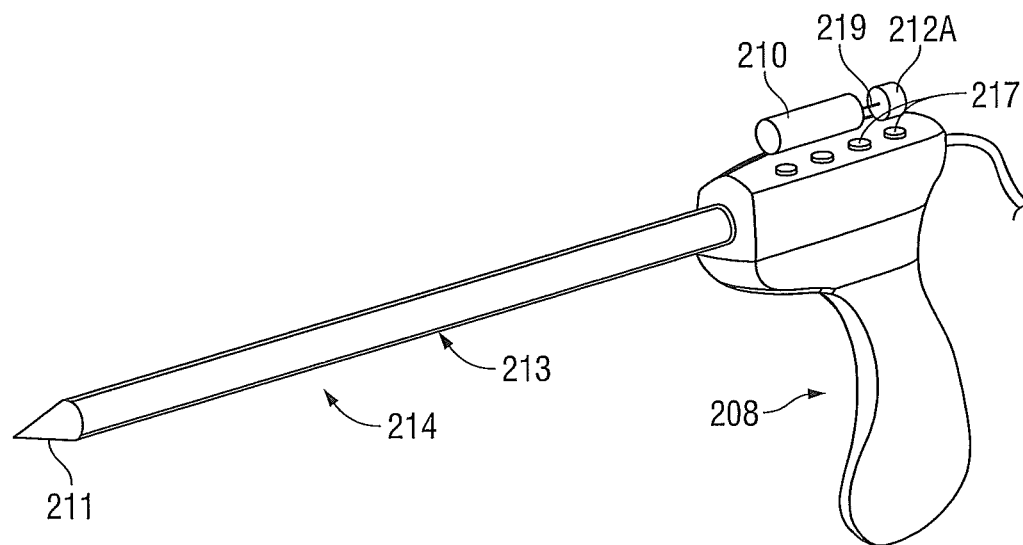


FIG. 3

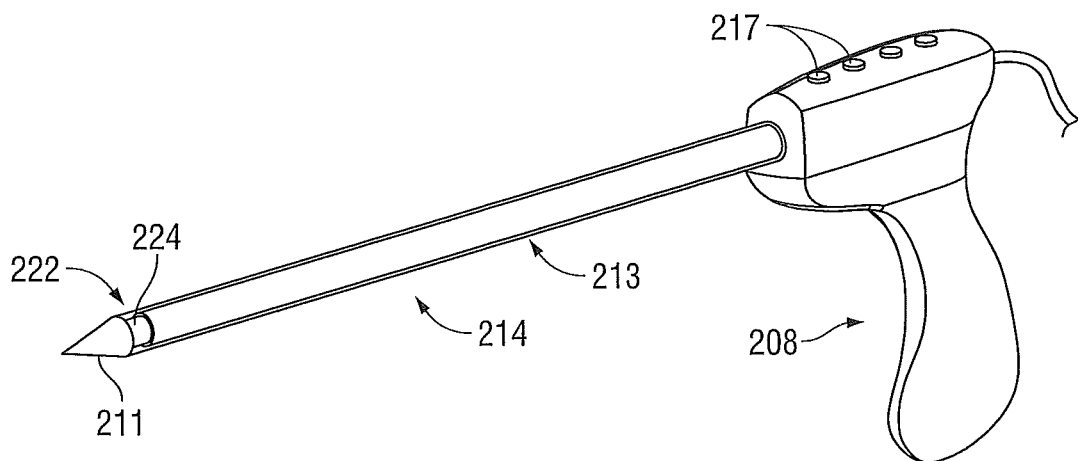


FIG. 4

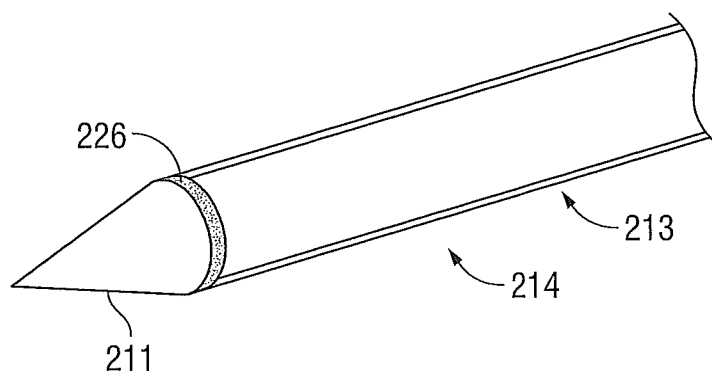


FIG. 5

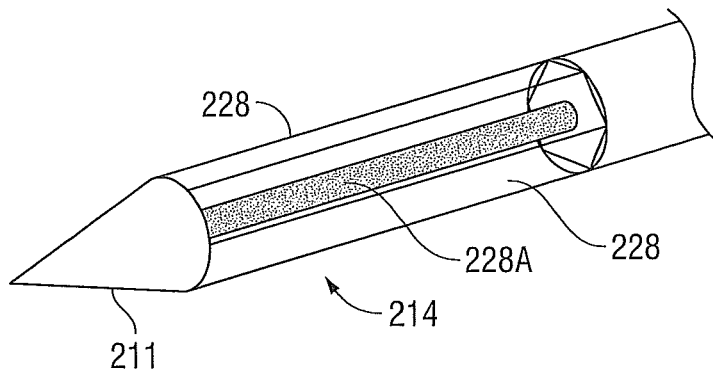


FIG. 6

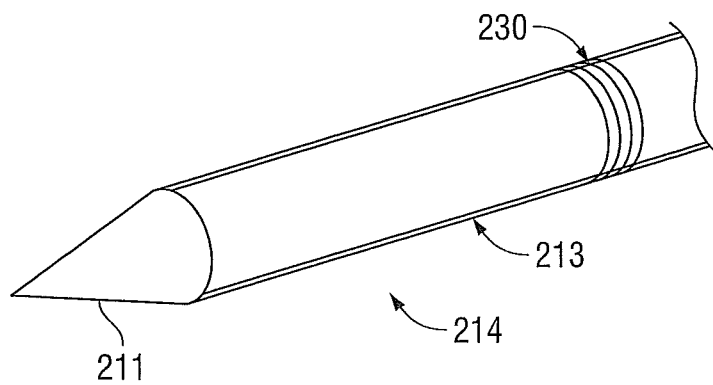


FIG. 7

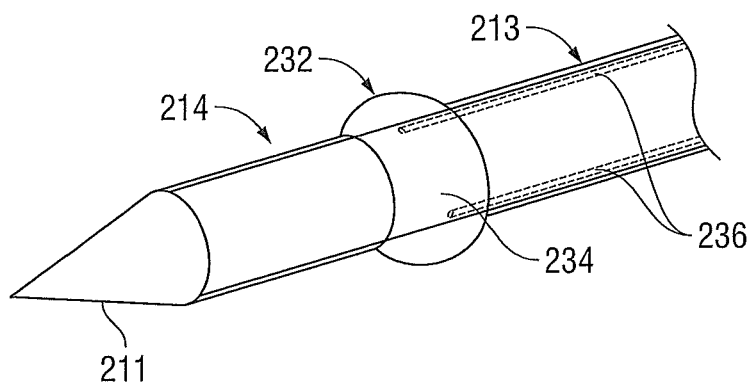


FIG. 8

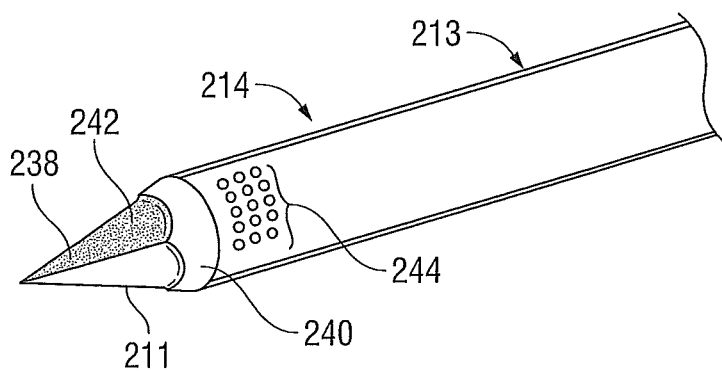


FIG. 9

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METHODS AND SYSTEMS FOR ENHANCING ULTRASONIC VISIBILITY OF ENERGY-DELIVERY DEVICES WITHIN TISSUE

CROSS REFERENCE TO RELATED APPLICATION

The present application claims the benefit of and priority to U.S. Provisional Application Ser. No. 61/664,555, filed on Jun. 26, 2012, the entire contents of which are incorporated herein by reference. The present application also claims the benefit of and priority to U.S. Provisional Application Ser. No. 61/664,577, filed on Jun. 26, 2012, the entire contents of which are incorporated herein by reference. The present application also claims the benefit of and priority to U.S. Provisional Application Ser. No. 61/664,559, filed on Jun. 26, 2012, the entire contents of which are incorporated herein by reference.

BACKGROUND

1. Technical Field

The present disclosure relates to electrosurgical devices suitable for tissue ablation applications and, more particularly, to methods and systems for enhancing ultrasonic visibility of energy-delivery devices within tissue.

2. Discussion of Related Art

Treatment of certain diseases requires the destruction of malignant tissue growths, e.g., tumors. Electromagnetic radiation can be used to heat and destroy tumor cells. Treatment may involve inserting ablation probes into tissues where cancerous tumors have been identified. Once the probes are positioned, electromagnetic energy is passed through the probes into surrounding tissue.

In the treatment of diseases such as cancer, certain types of tumor cells have been found to denature at elevated temperatures that are slightly lower than temperatures normally injurious to healthy cells. Known treatment methods, such as hyperthermia therapy, heat diseased cells to temperatures above 41° C. while maintaining adjacent healthy cells below the temperature at which irreversible cell destruction occurs. These methods involve applying electromagnetic radiation to heat, ablate and/or coagulate tissue. Microwave energy is sometimes utilized to perform these methods. Other procedures utilizing electromagnetic radiation to heat tissue also include coagulation, cutting and/or ablation of tissue.

Electrosurgical devices utilizing electromagnetic radiation have been developed for a variety of uses and applications. A number of devices are available that can be used to provide high bursts of energy for short periods of time to achieve cutting and coagulative effects on various tissues. There are a number of different types of apparatus that can be used to perform ablation procedures. Typically, microwave apparatus for use in ablation procedures include a microwave generator that functions as an energy source, and a microwave surgical instrument (e.g., microwave ablation probe) having an antenna assembly for directing energy to the target tissue. The microwave generator and surgical instrument are typically operatively coupled by a cable assembly having a plurality of conductors for transmitting microwave energy from the generator to the instrument, and for communicating control, feedback and identification signals between the instrument and the generator.

There are several types of microwave probes in use, e.g., monopole, dipole and helical, which may be used in tissue ablation applications. In monopole and dipole antenna

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assemblies, microwave energy generally radiates perpendicularly away from the axis of the conductor. Monopole antenna assemblies typically include a single, elongated conductor. A typical dipole antenna assembly includes two elongated conductors that are linearly-aligned and positioned end-to-end relative to one another with an electrical insulator placed therebetween. Helical antenna assemblies include helically-shaped conductor configurations of various dimensions, e.g., diameter and length. The main modes of operation of a helical antenna assembly are normal mode (broadside), in which the field radiated by the helix is maximum in a perpendicular plane to the helix axis, and axial mode (end fire), in which maximum radiation is along the helix axis.

During certain procedures, a probe may be inserted directly into tissue, inserted through a lumen, e.g., a vein, needle or catheter, or placed into the body using surgical techniques. Multiple probes may be used to synergistically create a large ablation or to ablate separate sites simultaneously.

Ultrasonography or computed tomography (CT) guidance may be used prior to ablation treatments for aiding probe placement. Ultrasonography is the imaging of deep structures in the body by recording the echoes of pulses of high frequency ultrasonic or sound waves directed into tissue and reflected by tissue planes where there is a change in density. A change in density exists along the plane or boundary between two types of tissue or between tissue and a non-anatomical structure, such as an energy-delivery device, such as, for example, an ablation probe within the tissue. Due to different acoustic impedances among the different types of anatomical structures, and non-anatomical structures within tissue, ultrasonography produces visual images of the anatomical and non-anatomical structures within the body.

However, during certain surgical procedures, it can be difficult to visualize an ablation probe, needle, catheter, etc. within the body using ultrasonography. As a result, it is difficult to guide surgical instruments to a proper location and/or position within the body, such as, for example, an ablation probe within a tissue mass to be ablated. Hence, techniques and improvements are needed to enhance the visualization of surgical instruments, especially, energy delivery devices, within tissue during ultrasonography.

SUMMARY

Various embodiments of the present disclosure provide methods and systems for enhancing ultrasonic visibility of energy-delivery devices. As used herein, the term “distal” refers to the portion that is being described which is further from a user, while the term “proximal” refers to the portion that is being described which is closer to a user. Further, to the extent consistent with one another, any of the aspects described herein may be used in conjunction with any of the other aspects described herein.

The term “ultrasonic visibility” is defined herein as the amount an object within tissue is visible or distinguishable from surrounding tissue during ultrasonography. The term “energy-delivery device” is defined herein to include any surgical instrument, device or apparatus capable of delivering energy to tissue, including, but not limited to, radiofrequency and microwave energy. Even though the present disclosure describes enhancing the ultrasonic visibility of an energy-delivery device, one skilled in the art can embody the novel aspects described herein to enhance the ultrasonic visibility of other devices which are inserted, implanted, guided, positioned, etc. within tissue, such as, for example, surgical patches, stents, metal rods, spinal implants, artificial joints, etc.

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In accordance with aspects of the present disclosure, electrosurgical systems are provided generally including at least one energy-delivery device for delivering energy to tissue when inserted or embedded within tissue. The energy-delivery device can be a tissue ablation device, such as an ablation probe, needle, etc. for ablating tissue as commonly known in the art. The electrosurgical systems include at least one structure and/or operational characteristic for enhancing ultrasonic visibility of the energy-delivery devices within tissue during ultrasonography.

According to the present disclosure, different aspects are disclosed for enhancing the ultrasonic visibility of at least one structure of the energy-delivery device, such as an ablation probe, during ultrasonography, which, in turn, aids in the positioning and placement of the energy-delivery device within tissue. The at least one structure can include, but not limited to, a shaft extending from a handle assembly or hub, an ablation probe, an ablation needle, a trocar at a distal end of an ablation probe, and a cooling jacket.

In one aspect of the present disclosure, ultrasonic visibility of the energy-delivery device, such as an ablation probe, within tissue is enhanced by mechanical vibration. According to this aspect of the present disclosure, an electrosurgical system is provided capable of performing tissue ablation. The electrosurgical system includes a handle assembly, an energy-delivery device at least partially housed within a shaft and extending from the handle assembly, and a high-speed motor. The electrosurgical system further includes controls for activating the energy-delivery device and the motor. The motor can be powered by a battery or by a generator powering the electrosurgical system. The electrosurgical system can also include controls for actuating a pump, such as a peristaltic pump, for circulating cooling fluid through the energy-delivery device. The controls can be provided on the handle assembly.

The motor is positioned within the handle assembly at a proximal end of the energy-delivery device. The motor is in operative mechanical communication via a mechanical linkage assembly with a weight, such as an eccentric weight, positioned inside the energy-delivery device at a distal end thereof.

During placement of the energy-delivery device within tissue or at anytime when enhanced ultrasonic visibility of the energy-delivery device within tissue is desired, the motor is actuated thereby causing vibration of the weight at the distal end of the energy-delivery device. The vibration of the weight causes the energy-delivery device to vibrate. The vibrating energy-delivery device enhances its ultrasonic visibility.

In a similar aspect of the present disclosure, the high speed motor is positioned on the handle assembly. A weight, such as an eccentric weight, is connected to the motor. When the motor is actuated, mechanical vibration energy is transferred or transmitted to the distal end of the energy-delivery device causing the energy-delivery device to vibrate. The vibrating energy-delivery device enhances its ultrasonic visibility.

Variations of the above described mechanical vibration aspects include at least one of adjusting the speed of the motor to determine the resonant frequency of the energy-delivery device, adjusting the speed of the motor to determine the harmonic frequency of the ultrasonic imaging system, and positioning the weight at a distal end of the energy-delivery device.

In still another aspect of the present disclosure, the electrosurgical system includes a controller, such as a processor, for performing at least two or more of the mechanical vibrating actions described above for vibrating the energy-delivery device, such as, for example, rapidly varying or sweeping the

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frequency to allow the energy-delivery device to continually pass through the resonant frequency of the energy-delivery device or harmonic frequency of the ultrasonic imaging system.

In similar aspects as those described above with respect to an electrosurgical system having a handle assembly, the electrosurgical system can be of the type having a hub, as opposed to a handle assembly, from which an energy-delivery device extends from. In such an electrosurgical system, the motor can be positioned on or within the hub for transferring mechanical vibration energy to the distal end of the energy-delivery device.

In another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by hydraulic vibration. According to this aspect of the present disclosure, the energy-delivery device of the electrosurgical system can be caused to vibrate by circulating cooling fluid. In a similar aspect of the present disclosure, ultrasonic visibility of the energy-delivery device of the electrosurgical system is enhanced by selectively blocking the fluid flow of the cooling fluid. This causes high pressure pulses in the fluid flow. The high pressure pulses, in turn, cause vibration of the energy-delivery device which enhances the ultrasonic visibility of the energy-delivery device.

In still another similar aspect of the present disclosure, controls can be used to control the speed of the pump. At higher pumping speeds, the fluid pressure of the circulating cooling fluid through the energy-delivery device is increased, thereby causing increased vibration of the energy-delivery device. The speed of the pump can also be adjusted in similar aspects of the present disclosure to determine the resonant frequency of the energy-delivery device or the harmonic frequency of the ultrasonic imaging system.

In another aspect of the present disclosure, the electrosurgical system includes a pulsating device in operative communication with the pump. The pulsating device rapidly alternates the direction of fluid flow for achieving maximum hydraulic pressure change within the energy-delivery device and vibration of the energy-delivery device. The vibration of the energy-delivery device enhances the ultrasonic visibility of the energy-delivery device.

In still another aspect of the present disclosure, the electrosurgical system is capable of performing at least two or more of the hydraulic vibrating actions described above for vibrating the energy-delivery device, such as, for example, blocking the fluid flow while a controller, such as a processor, rapidly varies or sweeps the frequency to allow the energy-delivery device to continually pass through the resonant frequency (or harmonic frequency) of the ultrasonic imaging system.

In another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by providing an air cavity at or near the distal end of the energy-delivery device, such as, for example, at or near the tip of an ablation probe, RF electrode or microwave antenna. The air cavity is created by creating a ring groove circumferentially around the energy-delivery device, such as, for example, circumferentially around an ablation probe, near the tip. The ring groove provides an air pocket. The air pocket can be created when heat shrink is placed over the top of the energy-delivery device. The air pocket enhances ultrasonic visibility of the energy-delivery device during placement, since air has a very high ultrasonic contrast compared to the surrounding tissue because of the difference in density and acoustic properties.

In still another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is

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enhanced by positioning a metal band to the energy-delivery device, such as, for example, positioning a metal band on a shaft or cooling jacket extending from a handle assembly, at a distal end of an ablation probe or needle, or between a trocar at a distal end of an ablation assembly and a cooling jacket. The metal band can be provided with small dimples to further enhance the ultrasonic visibility of the energy-delivery device.

In yet another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by making the shape of a cooling jacket or shaft of the energy-delivery device multi-sided, such as, for example, making the outer surface of the energy-delivery device hexagonal. The cooling jacket or shaft can be made multi-sided at or near the region of the radiating section of the energy-delivery device, such as at or near the distal end of an ablation probe. The flat or substantially flat sides of the cooling jacket or shaft enhance the ultrasonic visibility of the energy-delivery device. The surface of at least one side can be made concave and/or be provided with small dimples for enhanced ultrasonic visibility of the energy-delivery device.

In another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by wrapping the energy-delivery device with multiple metallic wires. The wires can be individual loops or wrapped in the form of a coil or spring. The wires are placed proximal to a radiating section of the energy-delivery device in order to aid in identifying the start of the radiating section without interfering with the emitted energy, such as microwave energy. The wires can also be placed over the active area of the radiating section in the case of an RF electrode, such as, a Cool-tip™ electrode.

In yet another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by adding fluid, such as a gel, liquid or gas, along an inner chamber of the shaft or within a sac or balloon positioned along the shaft. The inner chamber, sac or balloon can be inflated with the fluid, e.g., air, when ultrasonic visibility of the energy-delivery device is desired. In one configuration, the fluid is added between a cooling jacket and an outermost heat shrink, such as a PET heat shrink, during ultrasonography. If a liquid is used as the fluid, the ultrasonic energy is absorbed and the liquid appears darker in contrast compared to surrounding tissue. If air is used as the fluid, the ultrasonic energy is reflected and the air appears brighter in contrast compared to surrounding tissue. The fluid can be added during guidance, positioning and placement of the energy-delivery device within tissue, and be removed during the ablation procedure. The sac or balloon can be positioned in the area proximal to a radiating section or on the radiating section of the energy-delivery device.

In another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by increasing ultrasound reflection at or near the distal end of the energy-delivery device, such as, for example, at a trocar. The ultrasound reflection is increased by creating a concave surface at the distal end and/or adding a plurality of dimples to the surface of the distal end. Ultrasonic visibility is also increased by making the trocar multi-sided.

The distal end can be made from ceramic material which is molded to have a concave surface and/or a plurality of dimples thereon. The concave surface and/or plurality of dimples increase the amount of ultrasonic energy which is reflected by the energy-delivery device, thereby enhancing its ultrasonic visibility. The dimples can also be added on a cooling jacket, shaft, heat shrink or other structure of the energy-delivery device.

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In another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by releasing bubbles in proximity to the radiating section or a distal end of the energy-delivery device. The bubbles increase ultrasound reflection at or near the distal end of the energy-delivery device. The bubbles can be produced through electrolysis using an anode and cathode arrangement.

Finally, in yet another aspect of the present disclosure, ultrasonic visibility of the energy-delivery device within tissue is enhanced by adding micro spheres or protrusions of a hard material, such as, ceramic, glass, stainless steel, etc., at or near the radiating section or a distal end of the energy-delivery device. The micro spheres or protrusions can also be added on a cooling jacket, shaft, heat shrink or other structure of the energy-delivery device.

According to the above aspects, the present disclosure provides an electrosurgical system which includes an energy-delivery device adapted to direct energy to tissue. The system further includes a vibrating device in mechanical communication with the energy-delivery device for transmitting vibrational energy to the energy-delivery device when the vibrating device is actuated. The vibrational energy causes the energy-delivery device to vibrate. The electrosurgical system further includes a weight connected to the vibrating device, such as an eccentric weight. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

The electrosurgical system further includes a hub connected to the energy-delivery device. The vibrating device can be positioned with the hub. The vibrating device is a motor.

The electrosurgical system further includes controls or a controller, such as a processor, for at least one of adjusting the speed of the vibrating device to determine a resonant frequency of the energy-delivery device, and adjusting the speed of the vibrating device to determine a harmonic frequency of an ultrasonic imaging system in operative communication with the electrosurgical system. The controller can also sweep the frequency of the vibrating device. At least one accelerometer is positioned at a distal end of the energy-delivery device.

The electrosurgical system further includes an assembly in fluid communication with a distal end of the energy-delivery device for delivering fluid to the distal end. The assembly enables bubbles to be released from the distal end.

The energy-delivery device includes an air cavity defined therein. The energy-delivery device can further include a metal band.

The energy-delivery device includes a wire wrapped around an outer surface of the energy-delivery device. The outer surface of the energy-delivery device can be multi-sided. The distal end of the energy-delivery device can include at least one of a plurality of dimples and a plurality of protrusions. The distal end of the energy-delivery device can include a concave surface.

The present disclosure also provides a method for increasing the ultrasonic visibility of an energy-delivery device of an electrosurgical system within tissue. The method includes providing the electrosurgical system with a vibrating device in mechanical communication with the energy-delivery device. The method also includes actuating the vibrating device for transmitting vibrational energy to the energy-delivery device during ultrasonography. The vibrational energy causes the energy-delivery device to vibrate, and thereby increasing the ultrasonic visibility of the energy-delivery device.

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The method further includes positioning the vibrating device with a handle assembly of the electrosurgical system.

The method further includes at least one of adjusting the speed of the vibrating device to determine a resonant frequency of the energy-delivery device, and adjusting the speed of the vibrating device to determine a harmonic frequency of an ultrasonic imaging system in operative communication with the electrosurgical system. The method can further include sweeping the frequency of the vibrating device.

In additional embodiment according to the present disclosure, an electrosurgical system is provided which includes an energy-delivery device adapted to direct energy to tissue; and a metal band positioned on the energy-delivery device. The metal band can be fixedly or removably positioned on the energy-delivery device. The metal band includes a plurality of dimples. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

In a further additional embodiment according to the present disclosure, an electrosurgical system is provided which includes an energy-delivery device adapted to direct energy to tissue. The energy-delivery device defines an air cavity at a distal end thereof. The energy-delivery device can be a probe having a trocar at the distal end, and wherein the air cavity is defined proximally to the trocar. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

An electrosurgical system is also provided according to another embodiment of the present disclosure which includes an energy-delivery device adapted to direct energy to tissue; and a balloon assembly having an inflatable balloon positioned on the energy-delivery device and at least one conduit in fluid communication with a fluid source for delivering and withdrawing fluid to the balloon for selectively inflating and deflating the balloon. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

An electrosurgical system is also provided according to another embodiment of the present disclosure which includes an energy-delivery device adapted to direct energy to tissue; and a hydraulic assembly. The hydraulic assembly includes a fluid source in fluid communication with a distal end of the energy-delivery device. The hydraulic assembly further includes a flow-control device for selectively blocking and unblocking fluid flow, or controlling the rate of fluid flow. The hydraulic assembly creates and transmits hydraulic energy to the energy-delivery device for vibrating the energy-delivery device. The flow-control device can be a valve. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

The electrosurgical system further includes a pulsating device in operative communication with the flow-control device. The pulsating device alternates the direction of fluid flow.

The present disclosure further includes a method according to another embodiment for increasing the ultrasonic visibility of an energy-delivery device of an electrosurgical system within tissue during ultrasonography. The method includes providing the electrosurgical system with a hydraulic assembly in fluid communication with a distal end of the energy-delivery device and a flow-control device. The method also includes controlling the flow-control device for selectively blocking and unblocking fluid flow, or controlling the rate of fluid flow, for creating and transmitting hydraulic energy to the energy-delivery device for vibrating the energy-delivery device. The flow-control device can be a valve or a pump. The energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

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The controlling step includes varying the speed of the flow-control device to selectively adjust the rate of the fluid flow. The controlling step creates and transmits the hydraulic energy in the form of high pressure pulses to the energy-delivery device. The controlling step is performed by a processor unit. The controlling step includes controlling the amount of time the fluid flow is blocked. The controlling step further includes controlling the rate of the fluid flow. The controlling step also includes controlling the flow-control device using temperature data received from at least one temperature sensor.

The method further includes positioning the flow-control device on the energy-delivery device. The method also includes utilizing the hydraulic assembly for cooling the energy-delivery device. Additionally, the method includes adjusting the speed of the flow-control device to determine the resonant frequency of the energy-delivery device or the harmonic frequency of an ultrasonic imaging system performing the ultrasonography.

The method also includes alternating the direction of fluid flow. Additionally, the method includes sweeping the frequency to allow the energy-delivery device to pass through the resonant frequency or harmonic frequency of the ultrasonic imaging system performing the ultrasonography.

BRIEF DESCRIPTION OF THE DRAWINGS

Objects and features of the presently-disclosed to methods and systems for enhancing ultrasonic visibility of energy-delivery devices within tissue will become apparent to those of ordinary skill in the art when descriptions of various embodiments thereof are read with reference to the accompanying drawings, of which:

FIG. 1A is a schematic diagram of an electrosurgical system having an energy-delivery device and a vibrating device positioned on a hub in accordance with an embodiment of the present disclosure;

FIG. 1B is a schematic diagram of an electrosurgical system having an energy-delivery device and a vibrating device positioned within a hub in accordance with an embodiment of the present disclosure;

FIG. 2 is a schematic diagram of an electrosurgical system having a handle assembly and a vibrating device positioned within the handle assembly in accordance with an embodiment of the present disclosure;

FIG. 3 is a schematic diagram of an electrosurgical system having a handle assembly and a vibrating device positioned on the handle assembly in accordance with an embodiment of the present disclosure;

FIG. 4 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device defining an air cavity in accordance with an embodiment of the present disclosure;

FIG. 5 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device with a metal band in accordance with an embodiment of the present disclosure;

FIG. 6 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device having a multi-sided distal end in accordance with an embodiment of the present disclosure;

FIG. 7 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device having a wire wrapped around an outer surface of the energy-delivery device in accordance with an embodiment of the present disclosure;

FIG. 8 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device having an inflatable balloon in accordance with an embodiment of the present disclosure; and

FIG. 9 is a schematic diagram of an electrosurgical system having a handle assembly and an energy-delivery device having a multi-sided trocar and protrusions at a distal end in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

Hereinafter, embodiments of the presently-disclosed methods and systems for enhancing ultrasonic visibility of energy-delivery devices (or other component) of an electrosurgical system within tissue are described with reference to the accompanying drawings. Like reference numerals may refer to similar or identical elements throughout the description of the figures.

This description may use the phrases “in an embodiment,” “in embodiments,” “in some embodiments,” or “in other embodiments,” which may each refer to one or more of the same or different embodiments in accordance with the present disclosure. For the purposes of this description, a phrase in the form “NB” means A or B. For the purposes of the description, a phrase in the form “A and/or B” means “(A), (B), or (A and B)”. For the purposes of this description, a phrase in the form “at least one of A, B, or C” means “(A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C)”.

In accordance with the present disclosure, electrosurgical systems are provided generally including at least one energy-delivery device for delivering energy to tissue when inserted or embedded within tissue. The electrosurgical systems include at least one structure and/or operational characteristic for enhancing ultrasonic visibility of the energy-delivery devices within tissue during ultrasonography.

Enhancing the ultrasonic visibility of the energy-delivery device using an ultrasonic imaging system is beneficial for aiding in the placement of the energy-delivery devices during percutaneous and surgical procedures. This is because there is very little ultrasonic contrast between the tissue and energy-delivery devices which makes it difficult to distinguish energy-delivery devices as they pass through the tissue.

The energy-delivery device can be a tissue ablation device, such as an ablation probe, needle, etc. for ablating tissue as commonly known in the art. The ablation probe, for exemplary purposes in describing the various embodiments of the present disclosure, is an ablation probe including a fluid-cooled antenna assembly.

Additionally, the electrosurgical system described herein for exemplary purposes includes a thermal-feedback that controls the rate of fluid flow to the ablation probe. It is contemplated that embodiments of the present disclosure for enhancing ultrasonic visibility of energy-delivery devices or other components of the electrosurgical system within tissue can be implemented, integrated and/or otherwise incorporated in other systems and energy-delivery devices which are not described or mentioned herein. The description of the embodiments of the present disclosure to certain systems, especially electrosurgical systems, is for exemplary purposes only and shall not be construed as limiting the embodiments described herein to only these systems and variants thereof. That is, for example, embodiments may be implemented using electromagnetic radiation at microwave frequencies or at other frequencies.

According to various embodiments, the electrosurgical system is designed and configured to operate between about 300 MHz and about 10 GHz. Systems for enhancing ultra-

sonic visibility of an energy-delivery device, as described herein, may be used in conjunction with various types of devices, such as microwave antenna assemblies having either a straight or looped radiating antenna portion, etc., which may be inserted into tissue to be treated.

Various embodiments of the presently-disclosed electrosurgical systems utilizing methods and systems for enhancing ultrasonic visibility of an energy-delivery device are suitable for microwave ablation and for use to pre-coagulate tissue for microwave ablation-assisted surgical resection. Although various methods and systems described herein below are targeted toward ablation and the complete destruction of target tissue, it is to be understood that methods for directing electromagnetic radiation may be used with other therapies in which the target tissue is partially destroyed or damaged, such as, for example, to prevent the conduction of electrical impulses within heart tissue.

FIG. 1A shows an electrosurgical system 10 according to an embodiment of the present disclosure that includes an energy-delivery device in the form of an ablation probe 100, an electrosurgical power generating source 28, e.g., a microwave or RF electrosurgical generator, and an electrolysis assembly 84 in fluid communication with a distal end of the energy-delivery device 100. The electrolysis assembly 84 enables the generation and release of bubbles at a distal end of the ablation probe 100 for enhancing ultrasonic visibility according to one embodiment of the present disclosure.

The bubbles are produced by the electrolysis assembly 84 through electrolysis using an anode and cathode arrangement. The bubbles enhance the ultrasonic visibility of the ablation probe 100 during ultrasonography. The bubbles reflect ultrasonic energy delivered by an ultrasonic generator during ultrasonography making them brighter in contrast compared to surrounding tissue and the ablation probe. Accordingly, by noticing the brighter contrast, one can determine the location and position of the distal end of the ablation probe 100 within tissue.

The electrosurgical system 10 further includes a feedback control system 14 operably associated with a coolant supply system 11. Probe 100 is operably coupled to the electrosurgical power generating source 28, and disposed in fluid communication with the coolant supply system 11.

In some embodiments, one or more components of the coolant supply system 11 may be integrated fully or partially into the electrosurgical power generating source 28. Coolant supply system 11, which is described in more detail later in this description, is adapted to provide coolant fluid “F” to the probe 100. Probe 100, which is described in more detail later in this description, may be integrally associated with a hub 142 configured to provide electrical and/or coolant connections to the probe 100.

In some embodiments, the electrosurgical system 10 includes one or more sensors capable of generating a signal indicative of a temperature of a medium in contact therewith (referred to herein as temperature sensors) and/or one or more sensors capable of generating a signal indicative of a rate of fluid flow (referred to herein as flow sensors). In such embodiments, the feedback control system 14 may be adapted to provide a thermal-feedback-controlled rate of fluid flow to the probe 100 using one or more signals output from one or more temperature sensors and/or one or more flow sensors operably associated with the probe 100 and/or conduit fluidly-coupled to the probe 100.

The probe 100 as shown by FIG. 1A includes a strain relief 200. The strain relief 200 is fixed to a surface of the hub 142 to counter mechanical stress when the probe 100 bends dur-

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ing an electrosurgical procedure. In some embodiments, the probe **100** may extend from a handle assembly as shown by several of the figures.

In embodiments according to the present disclosure, as shown by FIGS. **1A** and **1B**, ultrasonic visibility of the energy-delivery device, such as the ablation probe **100**, within tissue is enhanced by mechanical vibration. The electrosurgical system **10** of FIG. **1A** is provided with a motor **202**. The motor **202** is positioned on hub **142** from which the ablation probe **100** extends from. The motor **202** can include an eccentric weight **204**. The motor **202** and eccentric weight **204** cause mechanical vibration energy to be transferred or transmitted from the proximal end of the ablation probe **100** to the distal end of the ablation probe **100** when the motor **202** is actuated. The mechanical vibration energy causes ablation probe **100**, including its distal end, to vibrate. A vibrating distal end of the ablation probe **100** has greater ultrasonic visibility than a non-vibrating distal end.

The motor **202** can also be positioned inside the hub **142** as shown by FIG. **1B**. When the motor **202** is positioned within the hub **142**, an eccentric weight **204A** can be provided at a distal end of the ablation probe **100**. The eccentric weight **204A** is mechanically connected to the motor **202** via a mechanical linkage assembly **206**, such as a rigid rod, designed to transfer mechanical vibration energy from the motor **202** to the eccentric weight **204A**. The mechanical vibration energy causes the eccentric weight **204A** at the distal end of the probe **100** to vibrate, and thereby impart vibrational energy to the distal end of the ablation probe **100**. The vibrational energy causes the ablation probe **100**, especially its distal end, to vibrate, and thereby increase the ultrasonic visibility of the probe **100**.

FIGS. **2-4** illustrate an electrosurgical system **10A** having a handle assembly **208**. In a first embodiment shown by FIG. **2**, the handle assembly **208** is provided therein with a motor **210**, similar to the embodiment shown by FIG. **1B**. The motor **210** can be a high speed motor as known in the art. The motor **210** is in operative communication with an eccentric weight **212** positioned at a distal end of an ablation probe **214**.

The eccentric weight **212** is mechanically connected to the motor **210** via a mechanical linkage assembly **216** designed to transfer mechanical vibration energy from the motor **210** through a longitudinal member **213**, such as a shaft or cooling jacket, of the probe **214** to the eccentric weight **212**. The linkage assembly **216** can include one or more rigid rods. The mechanical vibration energy causes the eccentric weight **212** to vibrate, and thereby impart vibrational energy to a distal end **211** of the ablation probe **214**. The vibrational energy causes the ablation probe **214**, especially its distal end **211**, to vibrate, and thereby increase the ultrasonic visibility of the probe **214**. The handle assembly **208** can include one or more controls **217** for operating the ablation probe **214** of the electrosurgical system, including actuating the motor **210** or other vibrating device during ultrasonography.

The motor **210** can also be on the handle assembly **208** as shown by FIG. **3**, similar to positioning the motor **210** on the hub **142** as shown by FIG. **1A**. When the motor **210** is positioned on the handle assembly **208**, an eccentric weight **212A** can be connected thereto via a mechanical connection **219**, such as at least one rigid rod. Activation of the motor **210** transfers mechanical vibration energy via a longitudinal member **213**, such as a shaft or cooling jacket, of the probe **214** to the distal end **211** of the probe **214**. The mechanical vibration energy causes the distal end **211** of the ablation probe **214** to vibrate, and thereby increase the ultrasonic

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visibility of the probe **214**. A vibrating distal end of the ablation probe **214** has greater ultrasonic visibility than a non-vibrating distal end.

Variations of the above described mechanical vibration embodiments include using the controls **217** or a controller, such as a processor, to perform at least one of the following: adjusting the speed of the motor or other vibrating device to determine the resonant frequency of the energy-delivery devices **100**, **214**, and adjusting the speed of the motor **210** to determine the harmonic frequency of the ultrasonic imaging system in operative communication with the electrosurgical system.

It is contemplated that the electrosurgical systems can include a controller, such as a processor, for performing at least two or more of the mechanical vibrating actions described above for vibrating the energy-delivery device, such as, for example, rapidly varying or sweeping the frequency to allow the energy-delivery device to continually pass through the resonant frequency of the energy-delivery device or harmonic frequency of the ultrasonic imaging system used for performing ultrasonography.

In embodiments, vibration of the energy-delivery device can be achieved by the use of other vibrating devices, besides a motor, capable of generating mechanical vibrational energy, such as micro-machines, IC chip, electromagnet, etc.

In the embodiments of the electrosurgical system **10** shown in FIGS. **1A** and **1B**, a processor unit **82** is disposed within or otherwise associated with the electrosurgical power generating source **28**. Processor unit **82** may be communicatively-coupled to one or more components or modules of the electrosurgical power generating source **28**, e.g., a user interface **121** and a generator module **86**. Processor unit **82** may additionally, or alternatively, be communicatively-coupled to one or more temperature sensors (e.g., two sensors "TS₁" and "TS₂" shown in FIGS. **1A** and **1B**) and/or one or more flow sensors (e.g., one sensor "FS₁" shown in FIGS. **1A** and **1B**) for receiving one or more signals indicative of a temperature (referred to herein as temperature data) and/or one or more signals indicative of a flow rate (referred to herein as flow data). Transmission lines may be provided to electrically couple the temperature sensors, flow sensors and/or other sensors, e.g., pressure sensors, to the processor unit **82**.

Electrosurgical power generating source **28** may include any generator suitable for use with electrosurgical devices, and may be configured to provide various frequencies of electromagnetic energy. In some embodiments, the electrosurgical power generating source **28** is configured to provide microwave energy at an operational frequency from about 300 MHz to about 10 GHz. In some embodiments, the electrosurgical power generating source **28** is configured to provide electrosurgical energy at an operational frequency from about 400 KHz to about 500 KHz.

Probe **100** may include one or more antennas of any suitable type, such as an antenna assembly (or antenna array) suitable for use in tissue ablation applications. For ease of explanation and understanding, the probe **100** is described as including a single antenna assembly **112**. In some embodiments, the antenna assembly **112** is substantially disposed within a sheath **138**. Probe **100** generally includes a coolant chamber **137** defined about the antenna assembly **112**. In some embodiments, the coolant chamber **137** includes an interior lumen defined by the sheath **138**.

Probe **100** may include a feedline **110** coupled to the antenna assembly **112**. A transmission line **16** may be provided to electrically couple the feedline **110** to the electrosurgical power generating source **28**. Feedline **110** may be coupled to a connection hub **142**, which is described in more

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detail later in this description, to facilitate the flow of coolant and/or buffering fluid into, and out of, the probe **100**.

In the embodiments shown in FIGS. 1A and 1B and in accordance with the present disclosure, the feedback control system **14** is operably associated with a flow-control device **50** disposed in fluid communication with a fluid flow path of the coolant supply system **11** (e.g., first coolant path **19**) fluidly-coupled to the probe **100**. Flow-control device **50** may include any suitable device capable of regulating or controlling the rate of fluid flow passing through the flow-control device **50**, or selectively blocking the fluid flow, e.g., a valve of any suitable type operable to selectively impede or restrict flow of fluid through passages in the valve, for among other purposes, causing hydraulic energy in the form of high pressure pulses to be transferred or transmitted to the ablation probe **100**.

The hydraulic energy is transferred or transmitted via the fluid flow path thorough the ablation probe **100** causing the ablation probe **100** to vibrate. The vibration of the ablation probe **100** enhances its ultrasonic visibility. It is envisioned that one or more additional flow-control devices can be positioned at different locations along the fluid flow path, including on the ablation probe **100**, for selectively blocking and unblocking the fluid flow for transferring hydraulic energy to the ablation probe **100**, especially to tapered portion **120** of the ablation probe **100**. The hydraulic energy causes vibration of the ablation probe **100** which enhances its ultrasonic visibility.

In embodiments, the flow-control device **50** may include a valve **52** having a valve body **54** and an electromechanical actuator **56** operatively-coupled to the valve body **54**. Valve body **54** may be implemented as a ball valve, gate valve, butterfly valve, plug valve, or any other suitable type of valve. In the embodiments shown in FIGS. 1A and 1B, the actuator **56** is communicatively-coupled to with the processor unit **82** via a transmission line **32**. Processor unit **82** may be configured to control the flow-control device **50** by activating the actuator **56** to selectively block fluid flow, or adjust the fluid flow rate in a fluid flow path (e.g., first coolant path **19** of the coolant supply system **11**) fluidly-coupled to the connection hub **142** to achieve a desired fluid flow rate. The amount of time the fluid flow is blocked or the desired fluid flow rate may be determined by a computer program and/or logic circuitry associated with the processor unit **82**. The amount of time the fluid flow is blocked or the desired fluid flow rate may additionally, or alternatively, be selected from a look-up table or determined by a computer algorithm.

In other embodiments according to the present disclosure, controls can be used to control the speed of a pump for creating high pressure pulses to be transferred or transmitted to the ablation probe **100**. For example, a multi-speed pump can be provided on the fluid flow path, similar to fluid-movement device **60** described further below, instead of a valve, and the processor unit **82** may be configured to vary the pump speed to selectively adjust the fluid flow rate to attain a desired fluid flow rate, and to selectively turn on and off the pump.

At higher pumping speeds, the fluid pressure of the circulating cooling fluid through the energy-delivery device is increased, thereby causing increased vibration of the energy-delivery device **100**. The speed of the pump can also be adjusted to determine the resonant frequency of the energy-delivery device **100** or the harmonic frequency of the ultrasonic imaging system performing the ultrasonography.

In another embodiment of the present disclosure, the electrosurgical system **10** includes a pulsating device in operative communication with the pump. The pulsating device rapidly alternates the direction of fluid flow for achieving maximum

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hydraulic pressure change within the energy-delivery device **100** and vibration of the energy-delivery device **100**. The vibration of the energy-delivery device **100** enhances the ultrasonic visibility of the energy-delivery device **100**.

In still another embodiment of the present disclosure, the electrosurgical system **10** performs at least two or more of the hydraulic vibrating actions described above for vibrating the energy-delivery device **100**, such as, for example, blocking the fluid flow while a controller, such as a processor, rapidly varies or sweeps the frequency to allow the energy-delivery device **100** to continually pass through the resonant frequency (or harmonic frequency) of the ultrasonic imaging system.

Processor unit **82** may also be configured to control the flow-control device **50** based on determination of a desired fluid flow rate using temperature data received from one or more temperature sensors (e.g., "TS₁" and "TS₂").

With continued reference to FIGS. 1A and 1B, electrosurgical system **10** includes a suitable pressure-relief device **40** disposed in fluid communication with the diversion flow path **21** which may allow the fluid-movement device **60** to run at a substantially constant speed and/or under a near-constant load (head pressure) regardless of the selective adjustment of the fluid flow rate in the first coolant path **19**. Utilizing the suitable pressure-relief device **40** disposed in fluid communication with the diversion flow path **21**, in accordance with the present disclosure, may allow the fluid-movement device **60** to be implemented as a single speed device, e.g., a single speed pump.

Feedback control system **14** may utilize data "D" (e.g., data representative of a mapping of temperature data to settings for properly adjusting one or more operational parameters of the flow-control device **50** to achieve a desired temperature and/or a desired ablation) stored in a look-up table, or other data structure, to determine the desired fluid flow rate. In the embodiments shown in FIGS. 1A and 1B, the electrosurgical system **10** includes a first temperature sensor "TS₁" capable of generating a signal indicative of a temperature of a medium in contact therewith and a second temperature sensor "TS₂" capable of generating a signal indicative of a temperature of a medium in contact therewith. Feedback control system **14** may be configured to utilize signals received from the first temperature sensor "TS₁" and/or the second temperature sensor "TS₂" to control the flow-control device **50**.

In some embodiments, the electrosurgical system **10** includes a flow sensor "FS₁" communicatively-coupled to the processor unit **82**, e.g., via a transmission line **36**. In some embodiments, the flow sensor "FS₁" may be disposed in fluid communication with the first coolant path **19** or the second coolant path **20**. Processor unit **82** may be configured to control the flow-control device **50** based on determination of a desired fluid flow rate using one or more signals received from the flow sensor "FS₁". In some embodiments, the processor unit **82** may be configured to control the flow-control device **50** based on determination of a desired fluid flow rate using one or more signals received from the flow sensor "FS₁" in conjunction with one or more signals received from the first temperature sensor "TS₁" and/or the second temperature sensor "TS₂". Although the electrosurgical system **10** shown in FIGS. 1A and 1B includes one flow sensor "FS₁", alternative embodiments may be implemented with a plurality of flow sensors adapted to provide a measurement of the rate of fluid flow into and/or out of the probe **100** and/or conduit fluidly-coupled to the probe **100**.

Electrosurgical system **10** may additionally, or alternatively, include one or more pressure sensors adapted to provide a measurement of the fluid pressure in the probe **100** and/or conduit fluidly-coupled the probe **100**. In some

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embodiments, the electrosurgical system **10** includes one or more pressure sensors (e.g., pressure sensor **70**) disposed in fluid communication with one or more fluid flow paths (e.g., first coolant path **19**) of the coolant supply system **11** as opposed to a pressure sensor disposed within the probe **100**, reducing cost and complexity of the probe **100**.

In the embodiments shown in FIGS. **1A** and **1B**, the processor unit **82** is operably associated with a pressure sensor **70** disposed in fluid communication with a fluid flow path of the coolant supply system **11**. Processor unit **82** may be communicatively-coupled to the pressure sensor **70** via a transmission line **30** or wireless link. Processor unit **82** may additionally, or alternatively, be operably associated with one or more pressure sensors disposed within the probe **100**, e.g., disposed in fluid communication with the coolant chamber **137**, for monitoring the fluid flow pressure within the probe **100**.

Pressure sensor **70** may include any suitable type of pressure sensor, pressure transducer, pressure transmitter, or pressure switch. Pressure sensor **70** (also referred to herein as “pressure transducer”) may include a variety of components, e.g., resistive elements, capacitive elements and/or piezoresistive elements, and may be disposed at any suitable position in the coolant supply system **11**. In some embodiments, the pressure transducer **70** is disposed in fluid communication with the first coolant path **19** located between the fluid-movement device **60** and the flow-control device **50**, e.g., placed at or near the flow-control device **50**.

In some embodiments, the processor unit **82** may be configured to control the flow-control device **50**, and/or other valve controlling fluid flow for transferring hydraulic energy to the ablation probe **100**, based on determination of a desired fluid flow rate using pressure data received from one or more pressure sensors and/or vibration data received from one or more accelerometers **232**. The one or more accelerometers can be positioned at a distal end of the probe **100** as shown by FIGS. **1A** and **1B**.

In some embodiments, the processor unit **82** may be configured to control the flow-control device **50** based on determination of a desired fluid flow rate using one or more signals received from the first temperature sensor “TS₁” and/or the second temperature sensor “TS₂” and/or the flow sensor “FS₁” in conjunction with one or more signals received from the pressure transducer **70** and/or one or more accelerometers **232**. The one or more accelerometers may be positioned on the probe **100** for monitoring the amount of vibration or displacement of the probe **100** from its axis, such as its longitudinal axis.

In some embodiments, the processor unit **82** may be configured to control the amount of power delivered to the antenna assembly **112** based on time and power settings provided by the user in conjunction with sensed temperature signals indicative of a temperature of a medium, e.g., coolant fluid “F”, in contact with one or more temperature sensors operably associated with the antenna assembly **112** and/or the connection hub **142**. In some embodiments, the processor unit **82** may be configured to decrease the amount of power delivered to the antenna assembly **112** when sensed temperature signals indicative of a temperature below a predetermined temperature threshold are received by processor unit **82**, e.g., over a predetermined time interval.

Processor unit **82** may be configured to control one or more operating parameters associated with the electrosurgical power generating source **28** based on determination of whether the pressure level of fluid in the probe **100** and/or conduit fluidly-coupled to the probe **100** is above a predetermined threshold using pressure data received from one or more pressure sensors, e.g., pressure transducer **70**.

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Examples of operating parameters associated with the electrosurgical power generating source **28** include without limitation temperature, impedance, power, current, voltage, mode of operation, and duration of application of electromagnetic energy.

In some embodiments, the output signal of the pressure transducer **70**, representing a pressure value and possibly amplified and/or conditioned by means of suitable components (not shown), is received by the processor unit **82** and used for determination of whether the pressure level of fluid in the probe **100** and/or conduit fluidly-coupled to the probe **100** is above a predetermined threshold in order to control when power is delivered to the antenna assembly **112**. In some embodiments, in response to a determination that the pressure level of fluid in the probe **100** and/or conduit fluidly-coupled to the probe **100** is below the predetermined threshold, the processor unit **82** may be configured to decrease the amount of power delivered to the antenna assembly **112** and/or to stop energy delivery between the electrosurgical power generating source **28** and the probe **100**. In some embodiments, the processor unit **82** may be configured to enable energy delivery between the electrosurgical power generating source **28** and the probe **100** based on determination that the pressure level of fluid in the probe **100** and/or conduit fluidly-coupled to the probe **100** is above the predetermined threshold.

In some embodiments, the pressure transducer **70** is adapted to output a predetermined signal to indicate a sensed pressure below that of the burst pressure of the pressure-relief device **40**. A computer program and/or logic circuitry associated with the processor unit **82** may be configured to enable the electrosurgical power generating source **28** and the flow-control device **50** in response to a signal from the pressure transducer **70**. A computer program and/or logic circuitry associated with the processor unit **82** may be configured to output a signal indicative of an error code and/or to activate an indicator unit **129** if a certain amount of time elapses between the point at which energy delivery to the probe **100** is enabled and when the pressure signal is detected, e.g., to ensure that the fluid-movement device **60** is turned on and/or that the probe **100** is receiving flow of fluid before the antenna assembly **112** can be activated.

As shown in FIGS. **1A** and **1B**, a feedline **110** couples the antenna assembly **112** to a connection hub **142**. Connection hub **142** may have a variety of suitable shapes, e.g., cylindrical, rectangular, etc. Connection hub **142** generally includes a hub body **145** defining an outlet fluid port **177** and an inlet fluid port **179**. Hub body **145** may include one or more branches, e.g., three branches **164**, **178** and **176**, extending from one or more portions of the hub body **145**. In some embodiments, one or more branches extending from the hub body **145** may be configured to house one or more connectors and/or ports, e.g., to facilitate the flow of coolant and/or buffering fluid into, and out of, the connection hub **142**.

In the embodiments shown in FIGS. **1A** and **1B**, the hub body **145** includes a first branch **164** adapted to house a cable connector **165**, a second branch **178** adapted to house the inlet fluid port **179**, and a third branch **176** adapted to house the outlet fluid port **177**. It is to be understood, however, that other connection hub embodiments may also be used. Examples of hub embodiments are disclosed in commonly assigned U.S. patent application Ser. No. 12/401,268 filed on Mar. 10, 2009, entitled “COOLED DIELECTRICALLY BUFFERED MICROWAVE DIPOLE ANTENNA”, and U.S. Pat. No. 7,311,703, entitled “DEVICES AND METHODS FOR COOLING MICROWAVE ANTENNAS”; the contents of both are incorporated herein by reference.

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In some embodiments, the flow sensor “FS₁” is disposed in fluid communication with the first coolant path 19, e.g., disposed within the inlet fluid port 179 or otherwise associated with the second branch 178, and the second temperature sensor “TS₂” is disposed in fluid communication with the second coolant path 20, e.g., disposed within the outlet fluid port 177 or otherwise associated with the third branch 176. In other embodiments, the second temperature sensor “TS₂” may be disposed within the inlet fluid port 179 or otherwise associated with the second branch 178, and the flow sensor “FS₁” may be disposed within the outlet fluid port 177 or otherwise associated with the third branch 176.

Coolant supply system 11 generally includes a substantially closed loop having a first coolant path 19 leading to the probe 100 and a second coolant path 20 leading from the probe 100, a coolant source 90, and the fluid-movement device 60, e.g., disposed in fluid communication with the first coolant path 19. In some embodiments, the coolant supply system 11 includes a third coolant path 21 (also referred to herein as a “diversion flow path”) disposed in fluid communication with the first coolant path 19 and the second coolant path 20. The conduit layouts of the first coolant path 19, second coolant path 20 and third coolant path 21 may be varied from the configuration depicted in FIGS. 1A and 1B.

In some embodiments, a pressure-relief device 40 may be disposed in fluid communication with the diversion flow path 21. Pressure-relief device 40 may include any type of device, e.g., a spring-loaded pressure-relief valve, adapted to open at a predetermined set pressure and to flow a rated capacity at a specified over-pressure. In some embodiments, one or more flow-restrictor devices (not shown) suitable for preventing backflow of fluid into the first coolant path 19 may be disposed in fluid communication with the diversion flow path 21. Flow-restrictor devices may include a check valve or any other suitable type of unidirectional flow restrictor or backflow preventer, and may be disposed at any suitable position in the diversion flow path 21 to prevent backflow of fluid from the diversion flow path 21 into the first coolant path 19.

In some embodiments, the first coolant path 19 includes a first coolant supply line 66 leading from the coolant source 90 to the fluid-movement device 60, a second coolant supply line 67 leading from the fluid-movement device 60 to the flow-control device 50, and a third coolant supply line 68 leading from the flow-control device 50 to the inlet fluid port 179 defined in the second branch 178 of the connection hub body 145, and the second coolant path 20 includes a first coolant return line 95 leading from the outlet fluid port 177 defined in the third branch 176 of the hub body 145 to the coolant source 90. Embodiments including the diversion flow path 21 may include a second coolant return line 94 fluidly-coupled to the second coolant supply line 67 and the first coolant return line 95. Pressure-relief device 40 may be disposed at any suitable position in the second coolant return line 94. The spacing and relative dimensions of coolant supply lines and coolant return lines may be varied from the configuration depicted in FIGS. 1A and 1B.

Coolant source 90 may be any suitable housing containing a reservoir of coolant fluid “F”. Coolant fluid “F” may be any suitable fluid that can be used for cooling or buffering the probe 100, e.g., deionized water, or other suitable cooling medium. Coolant fluid “F” may have dielectric properties and may provide dielectric impedance buffering for the antenna assembly 112. Coolant fluid “F” may be a conductive fluid, such as a saline solution, which may be delivered to the target tissue, e.g., to decrease impedance and allow increased power to be delivered to the target tissue. A coolant fluid “F” composition may vary depending upon desired cooling rates and

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the desired tissue impedance matching properties. Various fluids may be used, e.g., liquids including, but not limited to, water, saline, perfluorocarbon, such as the commercially available Fluorinert® perfluorocarbon liquid offered by Minnesota Mining and Manufacturing Company (3M), liquid chlorodifluoromethane, etc. In other variations, gases (such as nitrous oxide, nitrogen, carbon dioxide, etc.) may also be utilized as the cooling fluid. In yet another variation, a combination of liquids and/or gases, including, for example, those mentioned above, may be utilized as the coolant fluid “F”.

In the embodiments shown in FIGS. 1A and 1B, the fluid-movement device 60 is provided in the first coolant path 19 to move the coolant fluid “F” through the first coolant path 19 and into, and out of, the probe 100. Fluid-movement device 60 may include valves, pumps, power units, actuators, fittings, manifolds, etc. The position of the fluid-movement device 60, e.g., in relation to the coolant source 90, may be varied from the configuration depicted in FIGS. 1A and 1B. Although the coolant supply system 11 shown in FIGS. 1A and 1B includes a single, fluid-movement device 60 located in the first coolant path 19, various combinations of different numbers of fluid-movement devices, variedly-sized and variedly-spaced apart from each other, may be provided in the first coolant path 19 and/or the second coolant path 20.

In some embodiments, the probe 100 includes a feedline 110 that couples the antenna assembly 112 to a hub, e.g., connection hub 142, that provides electrical and/or coolant connections to the probe 100. Feedline 110 may be formed from a suitable flexible, semi-rigid or rigid microwave conductive cable. Feedline 110 may be constructed of a variety of electrically-conductive materials, e.g., copper, gold, or other conductive metals with similar conductivity values. Feedline 110 may be made of stainless steel, which generally offers the strength required to puncture tissue and/or skin.

In some variations, the antenna assembly 112 includes a distal radiating portion 105 and a proximal radiating portion 140. In some embodiments, a junction member (not shown), which is generally made of a dielectric material, couples the proximal radiating section 140 and the distal radiating section 105. In some embodiments, the distal and proximal radiating sections 105, 140 align at the junction member and are also supported by an inner conductor (not shown) that extends at least partially through the distal radiating section 105.

Antenna assembly 112 or probe 214 may be provided with an end cap or tapered portion 120, which may terminate in a sharp tip 123 to allow for insertion into tissue with minimal resistance. One example of a straight probe with a sharp tip that may be suitable for use is commercially available under the trademark EVIDENT™ offered by Covidien. The end cap or tapered portion 120 may include other shapes, such as, for example, a tip 123 that is rounded, flat, square, hexagonal, or cylindroconical. End cap or tapered portion 120 may be formed of a material having a high dielectric constant, and may be a trocar.

Sheath 138 generally includes an outer jacket 139 defining a lumen into which the antenna assembly 112, or portion thereof, may be positioned. In some embodiments, the sheath 138 is disposed over and encloses the feedline 110, the proximal radiating portion 140 and the distal radiating portion 105, and may at least partially enclose the end cap or tapered portion 120. The outer jacket 139 may be formed of any suitable material, such as, for example, polymeric or ceramic materials. The outer jacket 139 may be a water-cooled catheter formed of a material having low electrical conductivity.

In accordance with the embodiments shown in FIGS. 1A and 1B, a coolant chamber 137 is defined by the outer jacket 139 and the end cap or tapered portion 120. Coolant chamber

137 is disposed in fluid communication with the inlet fluid port **179** and the outlet fluid port **177** and adapted to circulate coolant fluid “F” therethrough, and may include baffles, multiple lumens, flow restricting devices, or other structures that may redirect, concentrate, or disperse flow depending on their shape. Examples of coolant chamber embodiments are disclosed in commonly assigned U.S. patent application Ser. No. 12/350,292 filed on Jan. 8, 2009, entitled “CHOKED DIELECTRIC LOADED TIP DIPOLE MICROWAVE ANTENNA”, commonly assigned U.S. patent application Ser. No. 12/401,268 filed on Mar. 10, 2009, entitled “COOLED DIELECTRICALLY BUFFERED MICROWAVE DIPOLE ANTENNA”, and U.S. Pat. No. 7,311,703, entitled “DEVICES AND METHODS FOR COOLING MICROWAVE ANTENNAS”, the contents of these references are incorporated herein by reference. The size and shape of the sheath **138** and the coolant chamber **137** extending therethrough may be varied from the configuration depicted in FIGS. 1A and 1B.

During microwave ablation, e.g., using the electrosurgical system **10**, the probe **100** is inserted into or placed adjacent to tissue and microwave energy is supplied thereto. Ultrasonography is used to accurately guide the probe **100** into the area of tissue to be treated in accordance with the present disclosure. Probe **100** may be placed percutaneously or atop tissue, e.g., using conventional surgical techniques by surgical staff. A clinician may pre-determine the length of time that microwave energy is to be applied. Application duration may depend on many factors such as tumor size and location and whether the tumor was a secondary or primary cancer. The duration of microwave energy application using the probe **100** may depend on the progress of the heat distribution within the tissue area that is to be destroyed and/or the surrounding tissue. Single or multiple probes **100** may be used to provide ablations in short procedure times, e.g., a few seconds to minutes, to destroy cancerous cells in the target tissue region.

A plurality of probes **100** may be placed in variously arranged configurations to substantially simultaneously ablate a target tissue region, making faster procedures possible. Multiple probes **100** can be used to synergistically create a large ablation or to ablate separate sites simultaneously. Tissue ablation size and geometry is influenced by a variety of factors, such as the energy applicator design, number of energy applicators used simultaneously, time and wattage.

In operation, microwave energy having a wavelength, λ , is transmitted through the antenna assembly **112**, e.g., along the proximal and distal radiating portions **140**, **105**, and radiated into the surrounding medium, e.g., tissue. The length of the antenna for efficient radiation may be dependent on the effective wavelength λ_{eff} which is dependent upon the dielectric properties of the medium being radiated. Antenna assembly **112**, through which microwave energy is transmitted at a wavelength λ , may have differing effective wavelengths λ_{eff} depending upon the surrounding medium, e.g., liver tissue as opposed to breast tissue.

In some embodiments, the electrosurgical system **10** includes a first temperature sensor “TS₁” disposed within a distal radiating portion **105** of the antenna assembly **112**. First temperature sensor “TS₁” may be disposed within or contacting the end cap or tapered portion **120**. It is to be understood that the first temperature sensor “TS₁” may be disposed at any suitable position to allow for the sensing of temperature. Processor unit **82** may be electrically connected by a transmission line **34** to the first temperature sensor “TS₁”. Sensing temperature signals indicative of a temperature of a medium

in contact with the first temperature sensor “TS₁” may be utilized by the processor unit **82** to control the flow of electrosurgical energy and/or the flow rate of coolant to attain the desired ablation.

Electrosurgical system **10** may additionally, or alternatively, include a second temperature sensor “TS₂” disposed within the outlet fluid port **177** or otherwise associated with the third branch **176** of the hub body **145**. Processor unit **82** may be electrically connected by a transmission line **38** to the second temperature sensor “TS₂”. First temperature sensor “TS₁” and/or the second temperature sensor “TS₂” may be a thermocouple, thermistor, or other temperature sensing device. A plurality of sensors may be utilized including units extending outside the tip **123** to measure temperatures at various locations in the proximity of the tip **123**.

As described in U.S. patent application Ser. No. 13/043,694, which is commonly-owned, a memory device in operable connection with the processor unit **82** can be provided. In some embodiments, the memory device may be associated with the electrosurgical power generating source **28**. The memory device may also be implemented as a storage device integrated into the electrosurgical power generating source **28**. In some embodiments, the memory device may be implemented as an external device communicatively-coupled to the electrosurgical power generating source **28**.

The processor unit **82** may be communicatively-coupled to the flow-control device **50**, e.g., via a transmission line, and may be communicatively-coupled to the fluid-movement device **60**, e.g., via a transmission line. In some embodiments, the processor unit **82** may be configured to control one or more operational parameters of the fluid-movement device **60** to selectively adjust the fluid flow rate in a fluid flow path (e.g., first coolant path **19**) of the coolant supply system **11**. In one non-limiting example, the fluid-movement device **60** is implemented as a multi-speed pump, and the processor unit **82** may be configured to vary the pump speed to selectively adjust the fluid flow rate to attain a desired fluid flow rate.

Processor unit **82** may be configured to execute a series of instructions to control one or more operational parameters of the flow-control device **50** based on determination of a desired fluid flow rate using temperature data received from one or more temperature sensors, e.g., “TS₁” and “TS₂”. The temperature data may be transmitted via transmission lines or wirelessly transmitted. One or more flow sensors may additionally, or alternatively, be communicatively-coupled to the processor unit **82**, e.g., via transmission lines. In some embodiments, signals indicative of the rate of fluid flow into and/or out of the probe **100** and/or conduit fluidly-coupled the probe **100** received from one or more flow sensors may be used by the processor unit **82** to determine a desired fluid flow rate. In such embodiments, flow data may be used by the processor unit **82** in conjunction with temperature data, or independently of temperature data, to determine a desired fluid flow rate. The desired fluid flow rate may be selected from a look-up table or determined by a computer algorithm stored within the memory device.

In some embodiments, an analog signal that is proportional to the temperature detected by a temperature sensor, e.g., a thermocouple, may be taken as a voltage input that can be compared to a look-up table for temperature and fluid flow rate, and a computer program and/or logic circuitry associated with the processor unit **82** may be used to determine the needed duty cycle of the pulse width modulation (PWM) to control actuation of a valve (e.g., valve **52**) to attain the desired fluid flow rate. Processor unit **82** may be configured to execute a series of instructions such that the flow-control device **50** and the fluid-movement device **60** are coopera-

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tively controlled by the processor unit **82**, e.g., based on determination of a desired fluid flow rate using temperature data and/or flow data, to selectively adjust the fluid flow rate in a fluid flow path (e.g., first coolant path **19**) of the coolant supply system **11**.

Feedback control system **14** may be adapted to control the flow-control device **50** to allow flow (e.g., valve **52** held open) for longer periods of time as the sensed temperature rises, and shorter periods of time as the sensed temperature falls. Electrosurgical system **10** may be adapted to override PWM control of the flow-control device **50** to hold the valve **52** open upon initial activation of the antenna assembly **112**. For this purpose, a timer may be utilized to prevent the control device **50** from operating for a predetermined time interval (e.g., about one minute) after the antenna assembly **112** has been activated. In some embodiments, the predetermined time interval to override PWM control of the flow-control device **50** may be varied depending on setting, e.g., time and power settings, provided by the user. In some embodiments, the electrosurgical power generating source **28** may be adapted to perform a self-check routine that includes determination that the flow-control device **50** is open before enabling energy delivery between the electrosurgical power generating source **28** and the probe **100**.

In embodiments, features described for the electrosurgical system **10** having energy-delivery device **100** may be provided to an electrosurgical system having a handle assembly, as the handle assembly **208** shown by FIGS. 2-4. Other embodiments described herein below with reference to energy-delivery device **214** can be provided to energy-delivery device **100** of the system **10** shown by FIGS. 1A and 1B, and vice versa. Still other embodiments of the present disclosure for increasing or enhancing the ultrasonic visibility of an energy-delivery device will be described with reference to FIGS. 4-9.

With reference to FIG. 4, there is shown an embodiment of the present disclosure where ultrasonic visibility of the energy-delivery device **214** of an electrosurgical system within tissue is enhanced by providing an air cavity or pocket **222** at or near the distal end **211** of the energy-delivery device **214**, such as, for example, before the tip of an ablation probe (as shown in FIG. 4), RF electrode or microwave antenna. The air cavity **222** is defined by a ring groove **224**. However, it is contemplated that the cavity **222** can be of any shape or configuration.

With continued reference to FIG. 4, the ring groove **224** is circumferentially positioned around the energy-delivery device **214**. The air cavity or pocket **222** can be created when heat shrink is placed over the top of the energy-delivery device **214**. The air cavity **222** enhances ultrasonic visibility of the energy-delivery device **214** during placement, since air has a very high ultrasonic contrast compared to the surrounding tissue because of the difference in density and acoustic properties.

With reference to FIG. 5, there is shown an embodiment for enhancing ultrasonic visibility of the energy-delivery device **214** within tissue by positioning a metal band **226** to the energy-delivery device **214**, such as, for example, positioning a metal band, either fixedly or removably positioned, on the shaft **213** extending from the handle assembly **208**, at a distal end of an ablation probe or needle. The metal band **226** can also be located between a trocar at a distal end **211** of an ablation assembly and a cooling jacket. The metal band **226** can be provided with small dimples to further enhance the ultrasonic visibility of the energy-delivery device. The metal band **226** reflects the ultrasonic waves generated during ultra-

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sonography and thereby, increases the ultrasonic visibility of the energy-delivery device **214**.

With reference to FIG. 6, there is shown still another embodiment for enhancing or increasing the ultrasonic visibility of the energy-delivery device **214** within tissue. In this particular embodiment, the shape of a cooling jacket or shaft **213** of the energy-delivery device **214** is multi-sided, instead of circular, such as, for example, hexagonal. The outer surface of the cooling jacket or shaft **213** can be made multi-sided at or near the region of the radiating section of the energy-delivery device **214**, such as at or near the distal end **211** of an ablation probe. The flat or substantially flat sides **228** of the cooling jacket or shaft **213** reflect the ultrasonic waves during ultrasonography, and thereby, enhance the ultrasonic visibility of the energy-delivery device **214**. The surface of at least one side **228A** can be made concave and/or be provided with small dimples to further enhance the ultrasonic visibility of the energy-delivery device **214**.

FIG. 7 illustrates a yet another embodiment of increasing or enhancing the ultrasonic visibility of the energy-delivery device **214** within tissue. In this embodiment, the cooling jacket or shaft **213** of the energy-delivery device **214** is provided with multiple metallic wires or one metallic wire which is coiled around the cooling jacket or shaft **213**. The wires **230** can be individual loops or wrapped in the form of a coil or spring. The wires **230** are placed proximal to a radiating section of the energy-delivery device **214** in order to aid in identifying the start of the radiating section without interfering with the emitted energy, such as microwave energy. The wires **230** can also be placed over the active area of the radiating section in the case of an RF electrode, such as, a Cool-tip™ electrode. The wires **230** reflect the ultrasonic waves generated during ultrasonography and thereby, increasing the ultrasonic visibility of the energy-delivery device **214**.

FIG. 8 shows another embodiment for enhancing the ultrasonic visibility of the energy-delivery device **214** within tissue. In this embodiment, ultrasonic visibility is enhanced by utilizing an inflatable balloon or air sac assembly **232**. The assembly **232** includes an inflatable air sac or balloon **234** and at least one conduit **236** in fluid communication with a fluid source (not shown) for delivering and withdrawing fluid (liquid, gas, gel, etc.) to the air sac **234**. The air sac **234** and the at least one conduit **236** are positioned along the shaft **213**. By delivering fluid to the air sac **234**, the air sac **234** inflates.

The fluid is delivered to the air sac **234** via the at least one conduit **236** when ultrasonic visibility of the energy-delivery device **214** is desired. It is also contemplated that the fluid is delivered to chamber positioned within the chamber, such as an inner chamber. In one configuration, the fluid is added between a cooling jacket and an outermost heat shrink, such as a PET heat shrink, during ultrasonography.

If a liquid is used as the fluid, the ultrasonic energy is absorbed and the liquid appears darker in contrast compared to surrounding tissue. If air is used as the fluid, the ultrasonic energy is reflected and the air appears brighter in contrast compared to surrounding tissue. The fluid can be added during guidance, positioning and placement of the energy-delivery device **214** within tissue, and be removed during the ablation procedure. The sac or balloon **234** can be positioned in the area proximal to a radiating section or on the radiating section of the energy-delivery device **214**. The sac **234** can be in fluid communication with cooling fluid, such that the cooling fluid is used to inflate the sac **234**.

In an additional embodiment, ultrasonic visibility of the energy-delivery device **214** within tissue is enhanced by increasing ultrasound reflection at or near the distal end **211**

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of the energy-delivery device **214**, such as, for example, at a trocar **238**. The ultrasound reflection can be increased at the distal end **211** by creating a concave surface **240** at the distal end **211** and/or adding a plurality of dimples **242** to the surface of the distal end. Ultrasonic visibility is also increased by making the trocar **238** multi-sided.

The distal end **211** can be made from ceramic material which is molded to have a concave surface and/or a plurality of dimples thereon. The concave surface and/or plurality of dimples increase the amount of ultrasonic energy which is reflected by the energy-delivery device **214**, thereby enhancing its ultrasonic visibility. The dimples can also be added on a cooling jacket, shaft, heat shrink or other structure of the energy-delivery device **214**.

In yet another embodiment, with continued reference to FIG. **9**, ultrasonic visibility of the energy-delivery device **214** within tissue is enhanced by adding micro spheres or protrusions of a hard material **244**, such as, ceramic, glass, stainless steel, etc., at or near the radiating section or a distal end **211** of the energy-delivery device **214**. The micro spheres or protrusions **244** can also be added on a cooling jacket, shaft, heat shrink or other structure of the energy-delivery device **214**.

The above-described methods and systems for enhancing ultrasonic visibility of energy-delivery devices or other components of electrosurgical systems may be used in conjunction with a variety of electrosurgical devices adapted for treating tissue. The above-described systems and methods may be suitable for a variety of uses and applications, including medical procedures, e.g., tissue ablation, resection, cautery, vascular thrombosis, treatment of cardiac arrhythmias and dysrhythmias, electrosurgery, etc.

It is envisioned that various aspects and features of the embodiments shown by the various figures and/or described herein can be combined to form additional embodiments of the electrosurgical system **10**. For example, probe **100** of electrosurgical system **10** can be provided with an air cavity at a distal end and/or a metal band as shown by the embodiments of FIGS. **4** and **5**, respectively.

Although embodiments have been described in detail with reference to the accompanying drawings for the purpose of illustration and description, it is to be understood that the inventive processes and apparatus are not to be construed as limited thereby. It will be apparent to those of ordinary skill in the art that various modifications to the foregoing embodiments may be made without departing from the scope of the disclosure.

What is claimed is:

1. An electrosurgical system, comprising:

an energy-delivery device adapted to direct energy to tissue and having a distal end;

at least one accelerometer disposed at the distal end of the energy-delivery device; and

a vibrating device in mechanical communication with the energy-delivery device for transmitting vibrational energy to the energy-delivery device when the vibrating device is actuated, the vibrational energy causing the energy-delivery device to vibrate.

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2. The electrosurgical system of claim **1**, further comprising a handle assembly, and wherein the vibrating device is coupled to the handle assembly.

3. The electrosurgical system of claim **1**, further comprising a weight connected to the vibrating device.

4. The electrosurgical system of claim **1**, wherein the energy-delivery device is selected from the group consisting of an electrode, a probe, and an antenna.

5. The electrosurgical system of claim **1**, further comprising a hub connected to the energy-delivery device, wherein the vibrating device is positioned with the hub.

6. The electrosurgical system of claim **1**, wherein the vibrating device is a motor.

7. The electrosurgical system of claim **1**, further comprising a controller configured to at least one of:

adjust a speed of the vibrating device to determine a resonant frequency of the energy-delivery device; or

adjust the speed of the vibrating device to determine a harmonic frequency of an ultrasonic imaging system in operative communication with the electrosurgical system.

8. The electrosurgical system of claim **1**, further comprising a controller for sweeping a frequency of the vibrating device.

9. The electrosurgical system of claim **1**, further comprising an assembly in fluid communication with the distal end of the energy-delivery device for delivering fluid to the distal end, and wherein the assembly enables bubbles to be released from the distal end.

10. An electrosurgical system, comprising:

an energy-delivery device adapted to direct energy to tissue and including an air cavity defined therein; and

a vibrating device in mechanical communication with the energy-delivery device for transmitting vibrational energy to the energy-delivery device to vibrate the energy-delivery device.

11. An electrosurgical system, comprising:

an energy-delivery device adapted to direct energy to tissue and including a metal band; and

a vibrating device in mechanical communication with the energy-delivery device for transmitting vibrational energy to the energy-delivery device to vibrate the energy-delivery device.

12. An electrosurgical system, comprising:

an energy-delivery device adapted to direct energy to tissue and including an outer surface, the outer surface including at least one of:

a plurality of sides;

a plurality of protrusions; or

a concave surface; and

a vibrating device in mechanical communication with the energy-delivery device for transmitting vibrational energy to the energy-delivery device to vibrate the energy-delivery device.

13. The electrosurgical system according to claim **12**, wherein the energy-delivery device further includes a wire wrapped around the outer surface.

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